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Thirty-Year Growth and Yield of a Ponderosa Pine Plantation in Arizona

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Growth and yield information was collected from 30-year-old ponderosa pine (*Pinus ponderosa*) trees in a plantation north of Flagstaff, Arizona. The plantation is typical of many planted on basalt derived soils in the 1960s and 1970s and thinned in the 1980s. The average tree was 6.7 in at breast height (bh) and 18 ft in height, with a volume of 2.4 ft^3. The plantation contained 214 trees, 52 ft^2 of basal area, and 517 ft^3 of volume per acre. Annual average height growth was 0.6 feet over the 30-year period but was more rapid once the trees reached bh. Annual average diameter growth at bh was 0.3 in over the last 21 years. Knowledge of plantation conditions and growth and yield are important for forest ecosystem management planning. Information can be used to develop, calibrate, and refine computer models for predicting stand growth and yield.

Keywords: ponderosa pine, plantation, growth, yield, Arizona

Introduction

In the 1960s and 1970s, the USDA Forest Service Southwestern Region embarked on a major reforestation program in Arizona and New Mexico to reestablish trees within areas where the forest had been destroyed or left understocked by wildfires during the previous decades.

Over 2 million seedlings were planted on about 3,400 acres on the Sitgreaves National Forest between 1961 and 1969 (D. Beal 1996 personal correspondence) and over 11.5 million seedlings were planted in Arizona and New Mexico from 1974 to 1976 (J. Shafer 1995 personal correspondence). Ponderosa pine (*Pinus ponderosa*) was the main species planted. While several artificial regeneration options were used, including direct seeding, tree planting was the most reliable method for regenerating ponderosa pine (Heidmann et al. 1977). This was particularly true where healthy nursery-grown trees were planted on well prepared sites from which livestock had been excluded (Heidmann 1988; Schubert 1974). However, even with care, mortality during the first decade after planting often was 30 to 40 percent because of adverse climatic conditions, fires, insects and diseases, damage by rodents and large wild ungulates, and competition with associated vegetation (Schubert 1974).

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Currently, many of the successful plantations are approximately 30-years old and many are approaching commercial size. A knowledge of plantation growth and yield is important in forest management planning, because it is the basis for managing existing stands of young trees and for planning and scheduling activities related to future plantations. Little information is available on the growth and yield of ponderosa pine plantations in Arizona. Information is available for thinned and unthinned natural stands that developed from the 1919 seed crop (Ronco et al. 1985; Schubert 1974), but this may not be directly comparable.

A ponderosa pine plantation north of the Fort Valley Experimental Forest provides an opportunity to document growth and yield on a typical north central Arizona site. While it would be best to have growth and yield information for longer periods of time and for a number of plantations, information from this plantation should be comparable to similar plantations on similar sites. Long-term observations and measurements that consider all ponderosa pine forest resources are also central to ecosystem and landscape management.

Study Area

Physical Characteristics

The 1.8 acre plantation is located in the Hart Prairie area on the Coconino National Forest 2 mi north of the Fort Valley Experimental Forest Headquarters and approximately 15 mi northwest of Flagstaff. The site is at 6,800 ft in elevation on soils derived from basalt parent material. The terrain is relatively flat with slopes averaging less than 5 percent. Average annual temperature at the Fort Valley Headquarters is 43 °F, with a monthly average range from 25 °F in January to 63 °F in July (Ronco et al. 1985). Twenty-nine percent of the 22 in of average annual precipitation falls in July and August.

The site is typical of the *P. ponderosa/Festuca arizonica* habitat type. The estimated site index is 65 ft at 100 years (Minor 1964), which, according to Schubert (1974), is in the Southwestern Region's Site Class 2 (site indices 55 to 74).

Site History

The plantation is located within a 1,800 acre part of Hart Prairie area that burned during a human-caused wildfire in 1948. The site was typical of the 114,000 acres requiring reforestation in the Flagstaff Ranger District in 1961 (Sweitzer 1964). At least 190,000 2- to 4-year-old seedlings were planted between 1961 and 1965 in the Hart Prairie area (J. Rolf 1995 personal correspondence).

Although, initial survival was satisfactory, there was concern about how to reduce mortality among the newly planted trees. The Rocky Mountain Station initiated experiments to assist forest managers improve tree survival. Some studies evaluated herbicides as a site preparation tool (Heidmann 1968, 1970), others examined mulching techniques (Heidmann 1963a; Heidmann et al. 1977). Damage by mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*) was also a concern (Heidmann 1972), and several studies evaluated deer repellents (Heidmann 1963b).

The experimental ponderosa pine plantation was established in 1966 and 1967 to evaluate 4 deer repellents and a control treatment (L. J. Heidmann unpublished report). Eight hundred 2-0 bare-rooted seedlings were planted each year. The 2 plantings represent a combined density of 889 trees per acre, which was higher than most planting operations of the period. The site was prepared by treating competing herbaceous vegetation with a dalapon (2,2-dichloropropionic acid) spray at a rate of 5 lbs active ingredient per acre[4]. Trees were planted by hand using planting bars. Initial tree survival was excellent, although there was some mortality attributed to pocket gophers (*Thomomys* spp.), and a small amount of damage caused by rabbits (*Sylvilagus* spp.) and mice (*Peromyscus* spp.) Survival for the first planting was 82 percent (656 trees) after 4 seasons, and for the second planting, it was 96 percent (768 trees) after 3 seasons. This represented a combined survival of 89 percent (791 trees per acre). There were no differences in browsing, total height, or survival among deer repellent and control treatments. Average annual height growth for all seedlings during the period of the repellent study was 2.5 in. A precommercial thinning operation was conducted in the experimental and adjacent plantations in 1984 under a contract administered by the Coconino National Forest (J. Rolf 1995 personal correspondence).

Methods

The experimental ponderosa pine plantation was remeasured in May 1995 to determine growth and yield.

[4] *Although this report discusses research involving pesticides, it does not imply that the pesticide has been registered or recommended for the use studied. Registration is necessary before any pesticide can be recommended. If not handled or applied properly, pesticides can be injurious to humans, domestic animals, desirable plants, fish, and wildlife. Always read and follow the directions on the pesticide container.*

Because the plantation was not part of a formal growth and yield study, these were the first measurements taken since the conclusion of the deer repellent study in 1970. The trees were approximately 30-years-old in May 1995; no attempt was made to differentiate between year of establishment. Total height and diameter at breast height (dbh) were measured on all surviving trees within the plantation using standard procedures. Height was measured to the nearest half foot and diameter was measured to the nearest tenth inch. These data were used to calculate basal area and volume in cubic feet using the formula for southwestern ponderosa pine (Myers 1963):

$$\text{Vol} = 0.001824 \cdot (\text{dbh}^2 \cdot \text{Ht}) + 0.58700$$

Stand density index (SDI) was calculated using a Reineke equation:

$$\text{SDI} = \text{N} \cdot (\text{ASD}/10)^{1.605}$$

where N = observed trees per acre
ASD = diameter of the tree with average basal area

SDI were calculated for each 1-in diameter class and then added to give a stand value. The SDI relates number of trees per acre to average dbh for even-aged stands (Husch et al. 1972).

Supplemental information was collected in 1996 on 5 one-twentieth acre plots within the plantation. Stumps of thinned trees were counted to give an estimate of thinning intensity. A subset of 10 dominant or codominant trees were arbitrarily selected from within the plots, and age at dbh was determined from increment cores. Stand densities appeared relatively uniform in the plantation and development of density-growth relationships were not attempted. The stumps of the thinned trees were sufficiently decayed to prevent an accurate determination of age relationships between stump and bh diameters or to reconstruct growth rates before the thinning operation.

Results

A total of 385 trees (equivalent to 214 trees per acre) were measured in 1995. This represents a long-term survival of 24 percent since establishment and 27 percent based on trees present at the conclusion of the deer repellent study. Data from the 5 plots indicate that at least 612 trees (340 trees per acre) were cut during precommercial thinning. The plantation contains about 52.3 ft^2 per acre of basal area and 516.8 ft^3 per acre of volume. This represents a periodic annual growth rate of 1.7 ft^2 and 17.2 ft^3 per acre for the surviving 30-year-old trees. The SDI based on a Reineke equation for ponderosa pine is 120.

The average dbh with standard deviation is 6.7 ± 2.1 in, and the range of diameters is from 0.3 to 11.3 in. A frequency distribution of the dbh values (figure 1) was developed using 1-in diameter classes (for example, the 5-in class includes all trees from 5.0 to 5.9 in at bh). Seventy-four percent of the trees are in the 5 to 9 in classes. The average dbh for the subset trees is 7.2 ± 1.4 in and the average age at bh is 21.4 ± 2.1 years, indicating an average annual diameter growth rate of 0.34 in.

The average total tree height is 18.5 ± 4.4 ft. The range is from 5.0 to 30.5 ft. The frequency distribution by 5 ft height classes (figure 2) indicates that the modal value is 20.0 ft and that most trees occur in the 20 and 25 ft classes.

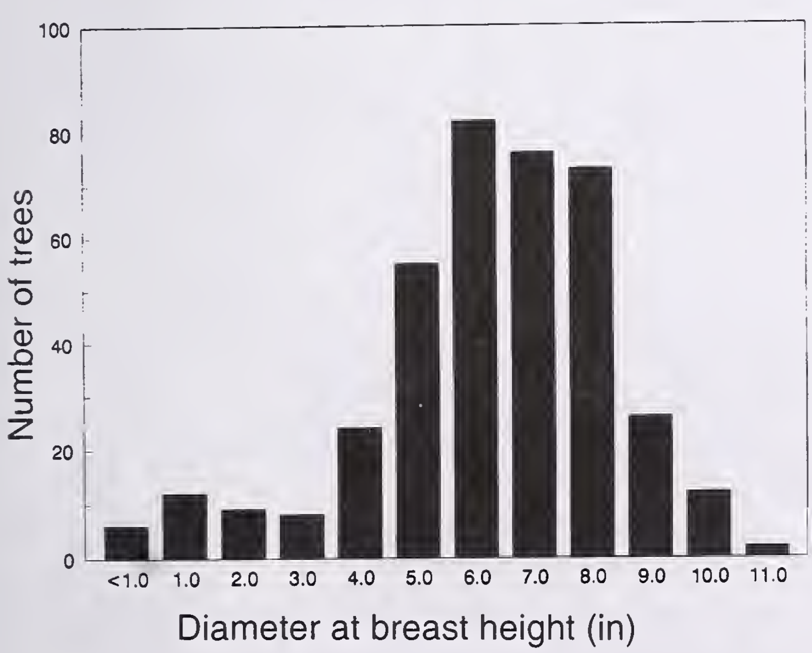

Figure 1. Distribution of trees in the Hart Prairie Plantation by diameter at breast height.

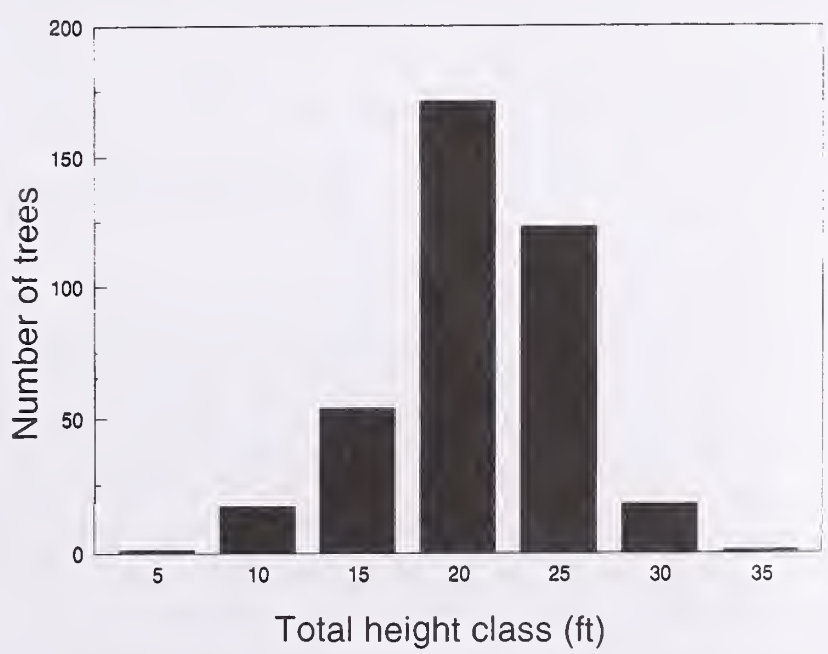

Figure 2. Distribution of trees in the Hart Prairie Plantation by total height class.

The 10-ft class, for example, includes trees from 5.5 to 10.0 ft. If we assume an average seedling height of 0.3 ft, the average tree has grown about 18.2 ft in height or about 0.6 ft a year. Calculations based on the subset of dominant and codominant trees, which average 20.9 ± 2.2 ft in height, indicate an average annual growth rate to bh of 0.49 ft, and from bh to present conditions of 0.77 ft. The average tree in this subset reached bh in about 9 years.

After 30 years, the total volume for the stand is 930.2 ft^3 or 516.8 ft^3 per acre. The average tree volume is 2.4 ± 1.2 ft^3. The highest volume of 7.4 ft^3 is in a tree with a dbh of 11.1 in and a total height of 30.5 ft. About 57 percent of the trees in the total stand contain at least 2 ft^3 of volume (figure 3). The 2-ft^3 class, for example, contains trees with 2.0 to 2.99 ft^3.

An important predictive tool in forest management is the diameter-height relationship. These data can be used to predict heights in similar stands when diameter, an easily measured parameter, is known. These relationships also can be used to compare growth and development among stands of the same age that are growing on different sites. The diameter-height relationship for the plantation (figure 4) is described by the equation:

$$\text{Height} = 6.10 + (1.86 \cdot \text{DBH})$$

$$r^2 = 0.79 \quad s_{yx} = 2.0$$

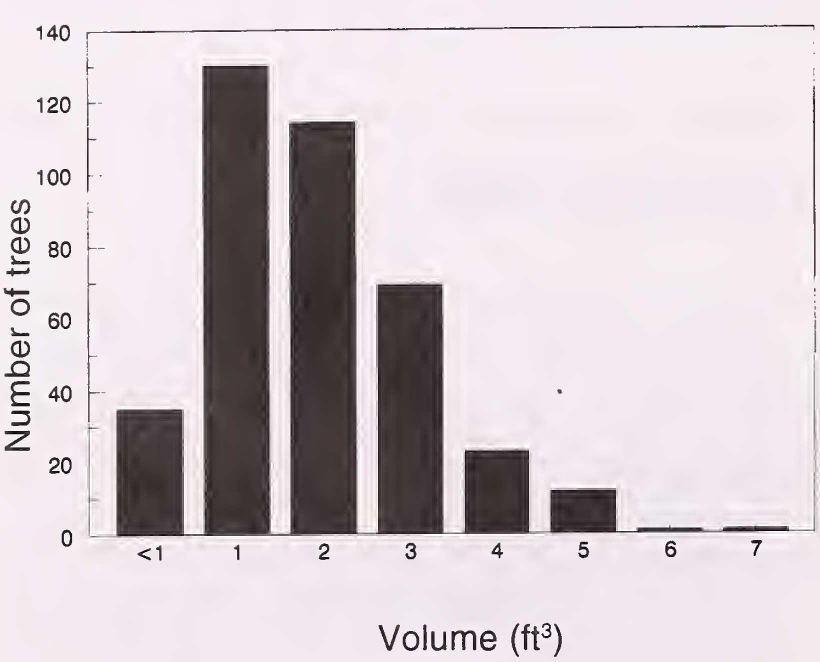

Figure 3. Distribution of trees in the Hart Prairie Plantation by total cubic foot volume.

Discussion

Basic information about the current status and initial growth and yield is lacking for most of the ponderosa pine plantations that were established in the 1960s and 1970s; however, this information is important for forest management. The present study at Hart Prairie provides an indication of conditions and stand and tree growth within a plantation on basaltic soils in Arizona.

Average diameter and tree density data can be used with the stand and growing stock level (GSL) tables developed by Schubert (1974) to predict conditions in fully stocked even-aged stands with average diameters up to 24 in. Growing stock levels are numerical index designations of the basal area that a residual stand has or will have when the average dbh of the residual stand is 10 in (Ronco et al. 1985). The current plantation, with an average dbh of 6.7 in and a density of 214 trees per acre, has a GSL of about 66. Managers could use the data to reduce present or future stocking to achieve a lower GSL goal or to maintain the present GSL. Both options could increase diameter growth of fewer residual trees. If the management goal is a GSL 60, for example, further reductions in the current plantation would be necessary. Sixty square ft per acre may be best for the range of resources including timber, runoff augmentation, and herbage production (Brown et

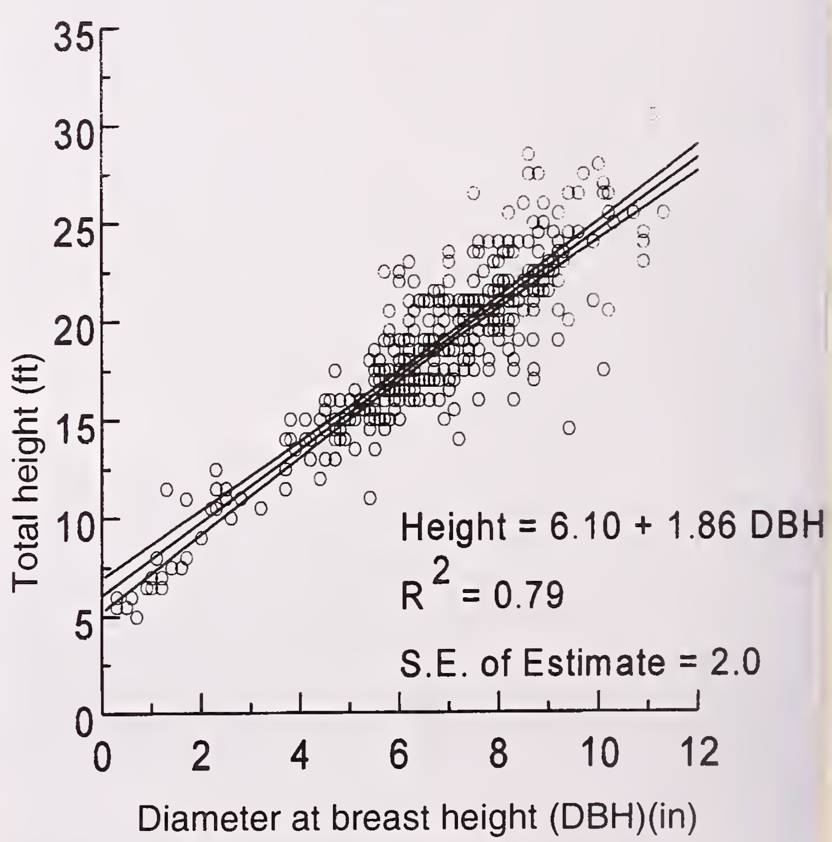

Figure 4. Diameter at breast height/total height relationship for an Arizona ponderosa pine plantation after 30 years.

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al. 1974). Based on tables in Schubert (1974), the current basal area would be reduced from 52 to 47 ft^2 per acre and the density to 193 trees per acre to achieve a GSL 60. The equations for Taylor Woods (Ronco et al. 1985) indicate that mean periodic annual diameter increment of residual trees consequently would increase by 0.014 in. Thinning operations would probably be delayed, however, until a commercial product could be obtained, even if some accelerated growth is lost.

Alternatively, existing trees would be retained if a greater GSL was needed. Even though growth would be slower, a GSL 80 would require that the 214 trees be retained until the average diameter was about 8.0 in. The Taylor Woods study indicated that GSLs of 80 and 100 appear to provide a compromise between volume production and stand density (Ronco et al. 1985). Schubert (1974) estimated that an even-aged ponderosa pine stand at GSL 80 would have an average dbh of 21 in and a gross volume of 7,200 ft^3 after 120 years. SDI values also are used for forest management planning. Taylor Woods growth data should be used with caution, however, because they were developed from thinning studies in natural pole stands that were established in 1919. It would be best if similar data were available for the 1960 to 1970 ponderosa pine plantations.

Predictions of forest resource responses and subsequent management decisions often are made using computer simulation models. Growth and yield information, such as presented here, can be used to validate, calibrate, and refine existing models. J. Shafer, the Forest Service's Southwestern Regional Silviculturist, ran the Hart Prairie information on the GENGYM Forest Vegetation Simulator (FVS) model (Edminster et al. 1991). The model predicted a 30-year total tree height of 19 ft, which is similar to the actual measurement, but predicted slower diameter growth than was actually measured. The model predicted an average diameter of about 4 in at 30 years (2/3 of the actual value) and a lower stand volume (1/4 of actual value) and basal area (1/3 of actual value). The model predicted a SDI of 50, lower than the SDI of 120 calculated for the existing stand. These results could be used to further calibrate the model.

The Hart Prairie plantation information provides a conservative indication of future growth in the next 30 years. The growth and yield values are, however, most accurate for the near future. Measurements of top growth are conservative because of slow growth during the establishment period. Growth in the future, baring unusual climatic or biotic events, would probably be more rapid. The same is true for diameter growth. Although the impacts of the 1984 thinning operation were not quantified, it should have resulted in better growth of surviving trees. While height growth does not accelerate significantly when stand densities are reduced, diameter and basal area growth would accelerate again, if additional cultural operations are conducted (Ronco et al. 1985; Schubert 1974). The Hart Prairie data would be useful in planning for the management of more recent or future plantations on similar sites in north central Arizona.

Conclusion

The 30-year-old ponderosa pine at Hart Prairie is representative of many reforestation efforts in Arizona and New Mexico. Unfortunately, information about the current status of these plantations or of growth and yields since establishment are generally unavailable. This information is vital for long-term forest management activities for wood products production and to attain multiresource ecosystem management goals. Long-term records are important for ecosystem management. Plantation data will help managers evaluate the success of thinning operations and determine if proposed treatments will be biologically and economically successful. Site and stand conditions could limit success.

Monitoring, the key to management, provides a history of the land and a base for planning the future. Selected plantations throughout the Southwest should be identified for long-term monitoring under a variety of treatment regimes. Monitoring designs need to be scientifically planned and carefully established to provide managers and researchers with accurate resource information. Such information could be useful in the development, validation, and refinement of predictive tools. Relatively large plantation areas should also be identified in standard compartment analyses and monitored accordingly. Data should be documented and entered into easily accessible electronic data bases for future reference.

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